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The Detector Development and Physics Program in sPHENIX Experiment at RHIC

Yongsun Kim for the sPHENIX collaboration

Department of Physics and Astronomy, Sejong University, 209 Neungdong-ro, Gwangjin-gu, Seoul, 05006, South Korea
Department of Physics, University of Illinois Urbana-Champaign 1110 W. Green, Urbana IL, 61801, USA

Abstract

The sPHENIX experiment at RHIC will collect high statistics proton-proton, proton-nucleus and nucleus-nucleus data, starting in the early 2020's. The sPHENIX capabilities enable state-of-the-art studies of jet modification, upsilon suppression and open heavy flavor production to probe the microscopic nature of the strongly-coupled Quark Gluon Plasma, and will allow a broad range of cold QCD studies. The sPHENIX detector will provide precision vertexing, tracking and electromagnetic and hadronic calorimetry in the central pseudorapidity region $|\eta| < 1.1$, with full azimuth coverage, at the full RHIC collision rate, delivering unprecedented data sets for hard probe tomography measurements at RHIC. In this talk, we will present a brief overview of the sPHENIX detector design with emphasis on calorimetry. The novel design of the sPHENIX calorimeters includes a tungsten/scintillating fiber electromagnetic calorimeter and two steel/scintillating tile hadronic calorimeter sections. The calorimeter has been optimized for upsilon and jet measurements in the high multiplicity environment of heavy-ion collisions. The design has been simulated in detail using GEANT4, and the simulations have extensively vetted against results obtained from the T-1044 test beam facility at FNAL. Both simulation data and test beam data, and the resulting jet physics performance, will be presented in this talk.

Keywords: sPHENIX, heavy ion collision, QGP, sPHENIX beam test, T-1044, quark matter 2018

1. Introduction

sPHENIX is a planned experiment at RHIC to study the Quark Gluon Plasma (QGP), a new state of QCD matter at high temperature, produced in ultra-relativistic heavy ion collisions. Existing RHIC and LHC results have detailed many novel properties of the QGP. To fully understand the microscopic dynamics that leads to these properties and to unravel the temperature dependence of those processes, it is essential to use scale dependent probes and to compare results obtained at very different collision energies. This aim was identified as a priority in the 2015 U.S. Nuclear Physics Long Range Plan[1]. sPHENIX will serve as a state-of-the-art detector for RHIC, providing results to complement those from the LHC. The experiment is designed to collect large samples of jets, upsilons and heavy-flavor hadrons. The detector will be fully installed at RHIC in 2022 to be ready for taking data from 2023. In this presentation, the test beam results for the prototypes of the calorimeters and of the vertex tracker are reported.

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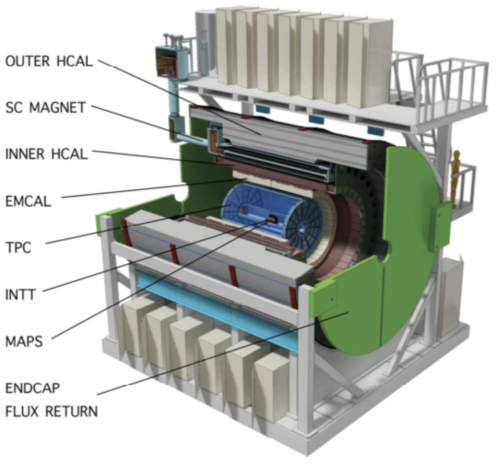

Fig. 1. Schematic view of the proposed sPHENIX detector
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2. sPHENIX Detector

The sPHENIX detector system is planned to be built in a cylindrical shape covering $|\eta| < 1.1$ with a full azimuth as shown in Fig. 1. The 3.5 m long superconducting solenoid, previously used in the BaBar experiment, will provide the magnetic field of 1.5 T to the tracking system out to 80 cm in radius followed by the electromagnetic calorimeter and the inner hadronic calorimeter. The tracking system for charged particles can be divided into components in order of vicinity from the beam pipe: (a) Monolithic Active Pixel Vertex detector (MVTX) (b) Silicon strip Intermediate Tracker (INTT) (c) Time Projection Chamber (TPC). The calorimeter system is designed to provide an excellent di-electron identification for upsilon, heavy flavor tagging and prompt photon/pion separation. The electromagnetic calorimeter (EMCal) is a composition of tungsten-scintillating fiber towers and read out modules made of silicon. Each tower has the granularity of $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$. The hadronic calorimeter (HCal) will be made of alternating layers of steel and scintillating tiles tilted in opposite directions such that a particle emitted from the interaction point can cross various scintillator layers. It will be 4.9 nuclear interaction lengths deep so can absorb more than 95% of an incident hadron shower. The granularity of a HCal tower is 0.1×0.1 and each of them corresponds to 4×4 EMCal towers. The outer HCal also surrounds the magnet cryostat serving as the magnet flux return. More details for the detector configuration can be found in Ref. [2].

3. T-1044: Beam test for calorimetry and MAPS

Increasingly refined prototypes of the EMCal and HCal have been tested at the Fermilab Test Beam Facility from 2014 in the title of T-1044 experiment. The primary goal was to understand the key parameters for calorimetry, such as the energy resolution and linearity of response. The 2017 beam test focused on the performance of EMCal and HCal towers at high pseudorapidity ($|\eta| = 0.9$). For EMCal, it was the first time to test the 2-d projective tower configuration for the block. In the previous T-1044 test in 2016 [3], the prototype had the geometry for the mid-rapidity region ($|\eta| = 0$) and the 1-d projective tower configuration. For electromagnetic inputs, electron beams in the range of 2-32 GeV were used while as hadronic inputs, charged pion beams (both for π^+ and π^-) were used. Cherenkov detectors were employed to reject the background particles. For the analysis of EMCal data, the energy calibration was done by position-dependent correction factors because a significant dependence of the energy response on the cluster position was observed. The positions of incident electrons were identified by two methods: (a) a scintillation hodoscope upstream from the EMCal was utilized or (b) the transverse shower shape was analyzed to find the energy weighted center of the cluster without the hodoscope. The results from both methods showed similar performance as shown in Fig. 2

The HCal prototype has 20 layers of scintillators each of which is divided into four tiles with embedded fibers for wavelength shifts. In the readout, a group of five tiles are bundled into a single tower, thus there are 16 towers in $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ covering the same phase space of the EMCal prototype. The linearity of the detector response and the resolution are studied as a function of incident energy and are shown in Fig. 2 for EMCal and in Fig. 3 for the combined EMCal+HCal configuration. When the incident beam enters the center of the towers, meaning that the transverse showers are fully covered by the prototype, the resolution for the electron energy was determined as $1.3\% \oplus 13.6/\sqrt{E}$ which meets the sPHENIX specification for reconstruction of electrons and prompt photons. The results of hadronic data also show that the resolution for a single particle satisfies the sPHENIX requirement which is $100\%/\sqrt{E}$. Besides, the test beam data exhibited an excellent agreement with the sPHENIX Monte Carlo studies based on GEANT4 simulation [4]. A new beam test was carried out in February and April of 2018 with the latest prototypes, and the data analysis is ongoing.

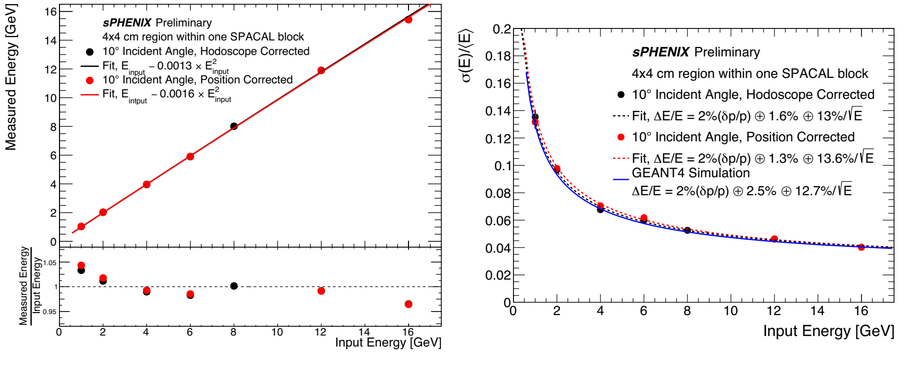

Fig. 2. The measurement of the linearity of the energy response (left) and resolution (right) of EMCal for electrons.

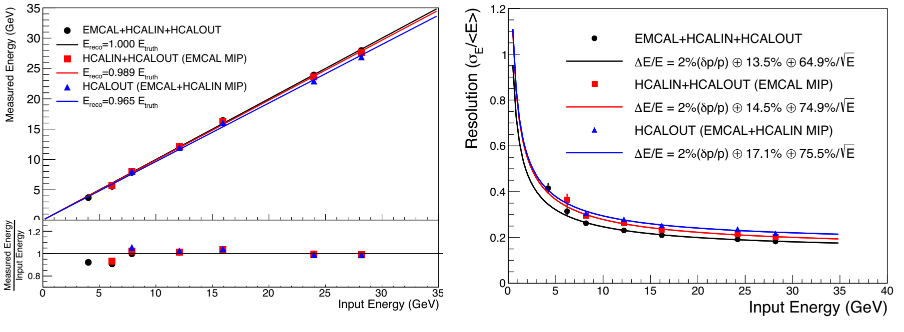

Fig. 3. Linearity (left) and the resolution measured with the combined EMCal and HCal configuration in three categories of the longitudinal shower profile of charged pions.

An important achievement of the 2018 beam test was the successful examination of the MVTX prototype. The MVTX detector will be installed in proximity of the beam pipe and will play the essential role to precisely measure the secondary vertex of particles decayed from heavy flavor hadrons. Fig. 4 shows a significant improvement of the vertexing capabilities by adding MVTX in the tracking system. This detector was being developed as a separate upgrade for the original sPHENIX proposal and designed by duplicating the ALICE Inner Tracking System (ITS) detector [5] as much as possible to secure a performance for heavy flavor reconstruction compatible with the LHC experiments. It is composed of 3 layers of 30 μm-wide pixel silicon tracker, resulting in the total radiation length of only 1%.

In the beam test, 4 telescope sensors were placed along the beamline of 120 GeV proton beam. Only the events with all four telescopes fired were selected to suppress the background. The full readout chain was also integrated to test the operation of data acquisition setup as well. Various parameters were tested including the cluster size, threshold parameters, and readout timing. The resolution of the hit position was determined to be less than 5 μm.

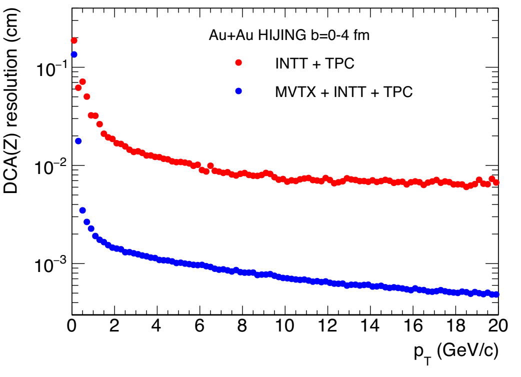

Fig. 4. Comparison of performance of secondary vertexing with and without MVTX component in the MC simulation.

4. Timeline of Experiment

The sPHENIX collaboration was formed in December 2015 and now comprises more than 70 institutions. The project received DOE CD-0 approval in September 2016 and had an official CD-1 review in June 2018. The construction and installation of the detector is expected to finish in 2022, to be ready for the first data taking in 2023. The collaboration's five-year physics plan consists of p+p, p+Au and Au+Au runs at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV.

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